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Influence of standard sections and time periods on optimization of a distribution network supplied by solar source

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Abstract. This paper shows the influence of cables standard sections and time periods on the location of solar energy generator, in order to optimize its distribution network. These parameters can influence considerably the whole cost of installation during the running of a project. An approach of resolution consists of determining the emplacement of the solar generator. For the electrical cables sections with a constant voltage drop, it is then placed in the electrical center of gravity 'E.G.C' of various loads that surrounds it. However, for cross sections which cover all installation conditions (standard sections), the generator is not in the gravity center (E.G.C), this optimal position (O.G.P) is known as having minimum of copper volume, that mean the least cost of cable for the complete installation. The determined standard sections for each cable, in this positions, are the smallest technically acceptable. An optimal section has been calculated in order to achieve the lowest annual cost of the investment. The obtained results prove that the adoption of this section has an effective economical profit in terms of energy gain.

Key words

Solar generator, network optimization, distribution network, cable cross section.

1. Introduction

The solar photovoltaic (PV), which is the direct conversion of sunlight into electricity, using solar cells, represents an attractive and well suited mean to produce energy [1]. In spite of its simplicity of implementation, its weak environmental impact and the low maintenance which it requires, a PV system is not competing any more when energy request increases, thus a rigorous study is necessary to make the best choice with the lowest possible costs [2].
The optimization of a solar installation based network is composed of two parts: the first is solar generators optimization, and the second is grid topology optimization. In our present work we are interested by the second part only. As from the moment when it is possible to implement solar collectors on a site, the choice of PV generator is essential, in order to create a suitable architecture of a distribution network, so it is important to be able to optimize the position of these generators, and to correctly calculate the cross sections of the cables used, indeed to, a small section will cause an overheating, and a loss of power, an excessive section may cause a weight and cost problem.
In the first part of our work [3]-[4], we determined the generator emplacement for a constant voltage drop by the technique of the electrical gravity center (E.G.C), which allows obtaining an optimal topology between the loads and the solar generator corresponding to a volume of the most optimal copper for cables used, and thus a fixed cost minimized. The method used is a determination of the E.G.C of a system consisting of electric loads (motors, buildings…) represented by points of various powers, where the E.G.C is at point (X_0, Y_0) [3]-[4].

$$X_0 = \frac{\sum_{i=1}^{n} X_i \times P_i}{\sum P_i} \quad (1)$$

$$Y_0 = \frac{\sum_{i=1}^{n} Y_i \times P_i}{\sum P_i} \quad (2)$$

Where (X_i, Y_i) represent the position of ith load in the site, and n the number of loads established on the site, *P* represents the consumption by ith load.
The position of the solar generator for an optimization of the quantity of copper and fixed cost of installation, relative to electrical loads and cables cross sections, is therefore determined. This position is realized by taking into consideration the heat losses and the influence of the maximum voltage drop technically acceptable. In our present work, we will consider in addition to these conditions, the thermal and standard cables sections on the one hand, and the variation of power loads with time periods on the other hand.
The objective of our work consists of optimizing the quantity of copper, and the heat losses of the electrical cables connected to a solar generator to decrease the maximum adjusted overall cost on the lifespan of the cable, according to the choice of electrical cable sections, and to the time periods influenced by the variations in the power consumed of each load. Therefore it is important to determine where we should place the solar energy based generator.

2. Standard section, S_d

In an electrical installation, the cable must support [5]:

-The design current (I_b), which is the current of required power in permanent, it is then the current to be carried in a circuit in normal service [6].

-The short circuit current (I_{sc}), until the protection intervention [7].

-The voltage drop (Δu) [8].

For each of these cases, there is respectively a specified section (permanent section (S_p), short-circuit section (S_{sc}), and a voltage drop section (S) [9]). The technical cross section to be selected for the used cables is the maximum normalized value among S_p, S_{sc} and S [5], it is then called standard section.

- *Thermal section, S_{th}*

The thermal section is the largest than the permanent section and the short-circuit section of the electrical used cable. In our case, the cables used are designed with copper a selected metal, and PVC an insulating material.

1) Permanent section, S_p

The permanent section is determined according to the method of the cross sections choice, that depends to currents (design current (I_b) [10], reference current I_r [11], the current-carrying capacity (I_z) [12]), and laying modes of cables with correction factors.

2) Short -circuit section, S_{sc}

The short-circuit section (S_{sc}), is determined according to the breaking time of the protective device used, which is less than five seconds.

$$S_{cc} = \frac{I_{sc}}{\delta_t} \quad (3)$$

I_{sc} . The maximum short-circuit current, amps (A).

The short-circuit current, can be calculated with different methods [7],in our case, where the generator is grouped in a single point, in view of the fact that the distances are not very large, it is calculated at the output of the inverter, it is directly taken to the datasheet of this one, as chosen in the formula (4) [13]

$$I_{sc,} = (2 \text{ à } 3) * I_n \quad (4)$$

I_n . Nominal current of the inverter, A .

$$\delta_t = \frac{\delta_0}{\sqrt{t}} \quad (5)$$

δ_t.. Current density withstand, A/mm²

δ_0. Short-circuit current density withstand for 1 second, A/mm².

t. Short-circuit time, s

The short-circuit current density withstand for one second, is function to the temperature allowed on core at end of short-circuit (θ_f), and to the core temperature at beginning of short-circuit (θ_d) [12]. The permanents and shorts-circuit sections, are constants for each power, the largest of both represents the cable thermal section connecting between the loads to the solar generator, as shown in table I. The thermal section for each electrical cable is constant for any solar generator position, a variation of the generator position only effect a voltage drop section (S), we will have then a different voltage drop section for each position of solar generator, and thus a different standard section also.

- *Numerical application*

Table. I, shows the calculated lengths and cross sections of electrical cables where the solar generator is placed in the center of gravity. In this example there are five different electrical loads (C1=32000W, C2=25000W, C3=18000W, C4=24000W, C5=25000W), whose Cartesian coordinates, are starting from a selected known origin.

Table. I. Calculating lengths and standards sections of electrical cables in the gravity center.

X (Km)	Y (Km)	P (w)	L (Km)	X0 (Km)	Y0 (Km)	I_b (A)	I_r (A)	I_z (A)	S (mm2)	S_p (mm²)	S_{sc} (mm²)	S_{th} (mm²)	S_d (mm²)
0,055	0,55	32000	0,364	0,317	0,297	57,803	78,113	80	64,027	16	2,622	16	70
0,505	0,055	37000	0,306	0,317	0,297	66,835	90,318	101	61,866	25	2,622	25	70
0,505	0,505	18000	0,279	0,317	0,297	32,514	43,938	60	25,168	10	2,622	10	35
0,305	0,285	24000	0,017	0,317	0,297	43,353	58,585	60	2,017	10	2,622	10	10
0,255	0,195	25000	0,12	0,317	0,297	45,159	61,026	80	14,625	16	2,622	16	16

3. Influence of standards sections (S_d) on the copper volume.

The Influence of standards sections (S_d) on the copper volume is indispensable, thus the position of solar generator is not in the gravity center because the minimum copper quantity does not correspond to this place.

- *Numerical application*

By using the Excel software calculator, we can determine and check the optimal place of solar generator according to cables standard sections, there for we searched the solar generator place for the minimum copper quantity, and thus we did a variation of its position starting from an origin, for this, we used our precedent example, where we varied the position of solar generator from the origin (X=0, Y=0), and calculated the sum of the product of lengths and standards sections of cables as shown in the first line of table II, the results show that the minimum quantity of copper for the electrical cables is not in the gravity center (X=0.317, Y=0.297), it is rather in the corresponding zone, that is to say, near the gravity center (X=0.32, Y=0.3), as shown in figure 1.

From this study and these results, we can say that the optimal place of solar generator is no longer in the gravity center (E.G.C). This optimal generator place (O.G.P) allows us to optimize the fixed cost of installation by optimizing the quantity of copper with the utilization of standards sections which cover all installation conditions.

Table. II. Influence of standards sections on the copper volume.

Solar generator positions		Load number one				Load number two				Load number three				Load number four				Load number five				Copper quantity
X	Y	L_1	S_{th1}	S_1	S_{d1}	L_2	S_{th2}	S_2	S_{d2}	L_3	S_{th3}	S_3	S_{d3}	L_4	S_{th4}	S_4	S_{d4}	L_5	S_{th5}	S_5	S_{d5}	$\sum_{i=1}^{5} L_i \times S_{d_i}$
0	0	0,552	16	106,4	120	0,507	25	115	120	0,714	10	71,8	95	0,417	10	53,68	70	0,321	16	41,81	50	0,24
0,317	0,297	0,364	16	64,03	70	0,306	25	61,9	70	0,279	10	25,17	35	0,017	10	2,017	10	0,12	16	14,63	16	0,0588
0,32	0,3	0,3643	16	63,969	70	0,307	25	62,1	70	0,276	10	24,84	25	0,021	10	2,402	10	0,123	16	15,05	16	0,056

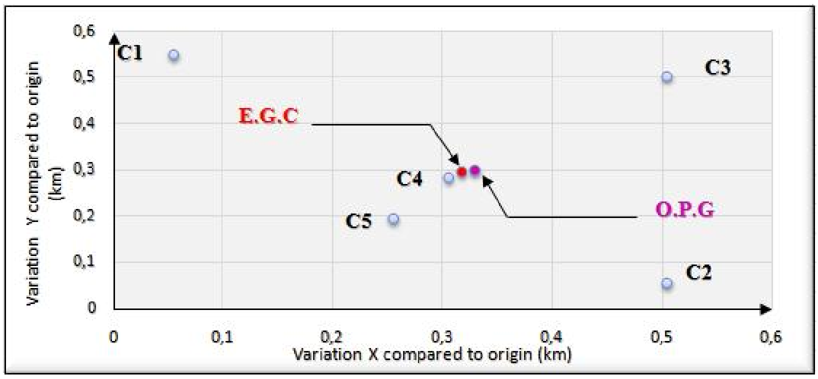

Fig. 1.Geographical positions of electrical loads and the new position of solar generator after application of standards section.

4. Influence of variations in the power consumed by each load according to the time periods.

The powers consumed by the loads, change according to the working hours or time periods. These changes don't influence the solar generator position for a copper quantity optimization while the standard section is based on full load power. It influence the economic section while the last depends on current loses.

Knowing that the resistance R of an electrical conductor is given by the formula (6) [14].

$$R = \frac{\rho \times L}{S} \tag{6}$$

Where ρ represents the resistivity, L the length and **S** the cable section (standard section).

In our site of 5 loads, with a solar generator placed in the optimal place, the heat losses $(R \times I^2)$ [15] for each cable is the sum of the several heats losses according to time periods of the working day, and the standard section of each cable is the smallest technically acceptable; the resistance is then maximum as shown in the equation (6). However the reduction of these losses is carried out by an increase in the standard section of the electrical cables, which can lead to optimize the exploitation cost. Indeed, by increasing the standard sections of electrical cables while keeping the position of the solar generator in the optimal place, the cables resistance decreases, so the electric losses also decrease, whereas the quantity of copper will increase. This observation allowed us to see an opposition between the exploitation cost and installation one (cable cost). An economic section must then be evaluated to decrease to the maximum the adjusted overall cost on the lifespan of the cable.

5. Economic section and its calculation method

The total cost evaluation of investment for the purchase, the installation of the cable and its use during the number of planned years of use is paramount. Indeed, the cable continues to cost money even after its installation and its utilization: its resistance permanently creates losses during its operation. The economic section is a function of parameters (electrical energy cost, number of service hours …) whose value varies during the period (N years) that is considered for the amortization of installation, the variations of these values cannot be specified during the establishment of the project.

The simplified calculates method that we present below, suppose that these parameters have a constant value during the considered period [16].

A. Law of purchase cost variation of the cable according to the section[16]

The purchase cost of the cable P (DA/km) according to the section S (mm²), can be calculated with several formulas, for make the demonstration easier, we admit that the cost representation is a straight line.

$$P = D + GS \tag{7}$$

$$\Rightarrow APL = A\,(D + GS)\,L \tag{8}$$

D and G are constants.

A. Annual amortization of the purchase cost of the cable.
L. Length of electrical cable, km.

B. Economic section for the case of a distribution network alimented by an infinite network , with standards sections

1) Amount of annual energy losses [16]

$$C1 = e n \rho \frac{LI^2 H}{S} 10^{-3} \quad (9)$$

C1. Annual amount of the heat losses in the conductors, DA.
e. Electrical energy cost, DA/kWh
I. Intensity to be transported, A.
H. Number of service hours of connection per year.
S. Standard section of a conductor, mm².
n. Active conductors number of the connection.
ρ. Resistivity of the conductive metal at the service temperature, Ωmm²/km.
L. Length of the connection, km.

2) Economic section, Se

The total cost C_{T1} of Annual profitability of the purchase, and annual amount of the energy losses has as an expression

$$C_{T1} = APL + C \quad (10)$$

$$C_{T1} = A(D + GS)L + \frac{en\rho H 10^{-3}}{S} \quad (11)$$

C_{T1} is minimum for the section (Se) such as

$$S_e = I\sqrt{\frac{en\rho H 10^{-3}}{AG}} \quad (12)$$

Practically the economic section is the closest of Se.

➢ *Numerical application*

We have then determined the economic sections of each electrical cable connected to the energy distributor of an infinite network, leading to the lowest total annual cost according to the volume of copper and exploitation cost by the relation (12), as shown in the table III.

Table III. - Economic sections calculation for a generator in an optimal place (O.G.P) alimented by an infinite network,

e(DA/Kwh)	n	ρ(Ωmm²/Km)	L (Km)	I (A)	H	G	A	S (mm²)	S_d (mm²)	S_e (mm²)
4	3	22,5	0,364	57,803	4000	54117,647	0,237	63,969	70	16,773
4	3	22,5	0,307	66,835	4000	54117,647	0,237	62,1	70	19,394
4	3	22,5	0,276	32,514	4000	54117,647	0,237	24,84	25	9,435
4	3	22,5	0,021	43,353	4000	54117,647	0,237	2,402	10	12,580
4	3	22,5	0,123	45,159	4000	54117,647	0,237	15,05	16	13,104

C. Economic section for the case of a distribution network alimented by solar source

1) Solar generator cost for energy losses with standard sections

The annual cost calculation (C2) of a solar generator according to the heat losses, for cables with standard sections, can be achieved by the following formula

$$C_2 = AJw \quad (13)$$

$$\rightarrow J = \frac{Pr_1 - Pr_2}{w_1 - w_2} \quad (14)$$

$$\rightarrow W = n\rho \frac{LI^2 H}{365\, S\, h} 10^{-3} \quad (15)$$

J. Is a constant.
Pr. Fixed cost of a solar generator, DA.
w_i. Power of i^th generator, kW.
W. Power required by the generator according to the heat losses, kW.
S. Standard section of a conductor, mm².
h. The daily number of sunshine hours.

2) Economic section, Se

The total cost C_{T2} of Annual profitability of the purchase, and annual amount of solar generator for energy losses has as an expression

$$C_{T2} = APL + C_2 \quad (16)$$

$$C_{T2} = A(D + GS)L + AJn\rho \frac{LI^2 H}{365\, S\, h} 10^{-3} \quad (17)$$

C_{T2} is minimum for the section (Se).

➢ *Numerical application*

By numerical method, we determined the economic sections for each cable connected to the solar generator. these sections are larger compared to the economic sections of an infinite network, considering that the kWh cost is higher, as shown in table V, where S_{ch} is the normalized economics sections.

We can explain this method by figure 2, where the representation of the cable cost according to the section is a right. Indeed the cost of a cable is higher when the standard section of the conductors is stronger.

The increase of exploitation cost is interpreted by a considerable increase of the number of PV modules to be used, which implies an increase of the electrical energy invoicing [15], the reduction of these losses by joule effect according to the increase in standard section, represents then an important profit of energy.

The sum of these two parameters determines the lowest annual cost (cable cost and exploitation cost), so its minimum indicates the most economic section (Se).

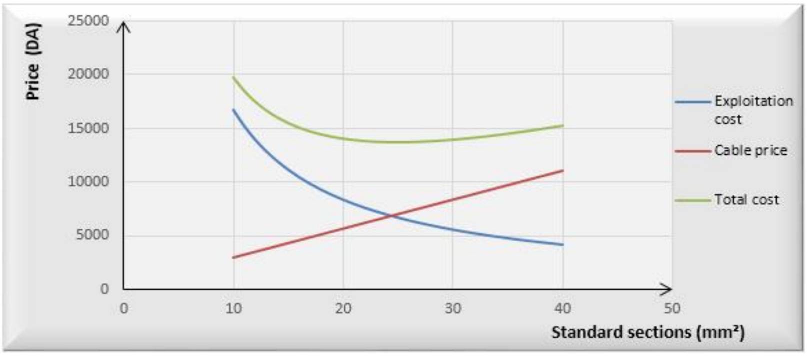

Fig. 2. The economic section numerical determination of a single electric load (C4).

Table V.-Economic sections for a generator in an optimal place (O.G.P), alimented by solar source (with standard sections, without time periods).

n	ρ(Ωmm²/Km)	L (Km)	I (A)	H	h	G	J	A	S (mm²)	S_d (mm²)	S_e (mm²)
3	22,5	0,364	57,803	4000	3,78	54117,647	91400	0,237	63,969	70	33
3	22,5	0,307	66,835	4000	3,78	54117,647	91400	0,237	62,1	70	38
3	22,5	0,276	32,514	4000	3,78	54117,647	91400	0,237	24,84	25	19
3	22,5	0,021	43,353	4000	3,78	54117,647	91400	0,237	2,402	10	25
3	22,5	0,123	45,159	4000	3,78	54117,647	91400	0,237	15,05	16	26

3) Solar generator cost for energy losses with standard sections and time periods.

The annual cost calculation (C3) of a solar generator according to the heat losses for loads with time periods, and cables with standard sections, can be achieved by the following formula

$$C_3 = AJw \tag{16}$$

$$W = n\frac{E_T}{365\,h}\,10^{-3} \tag{17}$$

$$E_T = E_j \times 250 \tag{18}$$

$$E_j = R\sum_{i=1}^{i=n} I^2_i\, ht_i \tag{19}$$

E_T. The total energy, kWh.
E_j. The daily energy, kWh.
ht. The working duration for the time period, hours.

➢ *Numerical application*

We could then determine the economic sections of cables connected to the solar generator, according to standard sections, and time periods for each electrical load, by the numerical method previously used. Our results show that the economic sections are influenced by time periods, as presented in table VI, where the economic sections are less than that whiteout time periods. However, the economic section with time periods may be equal to that without time periods, only if the load work in its full load each time period.

Table VI.-Economic sections for a generator in the optimal place (O.G.P), alimented by solar source (with standard sections and time periods).

n	ρ(Ωmm²/Km)	L (Km)	E_t(Wh)	H	h	G	J	A	S (mm²)	S_d (mm²)	S_e (mm²)
3	22,5	0,364	300064	4000	3,78	54117,647	91400	0,237	63,969	70	15
3	22,5	0,307	246667	4000	3,78	54117,647	91400	0,237	62,1	70	14
3	22,5	0,276	290862	4000	3,78	54117,647	91400	0,237	24,84	25	10
3	22,5	0,021	91634,5	4000	3,78	54117,647	91400	0,237	2,402	10	13
3	22,5	0,123	280649	4000	3,78	54117,647	91400	0,237	15,05	16	12

6. Result

The cross sections selected for the investment of our installation are the largest compared with the standard sections (S_d) and economic (Se), we called them the optimal sections. We could ask for a priori, why a larger cross section can lead ultimately to a lower cost.

This is due to the fact that in certain cases, even if the cable is more expensive to purchase it is more economical to use, considering its reduced resistance (less losses), over several years of use, the cost of the gained value on losses can compensate a larger initial investment [16].

In our case, to adopt the optimal sections, for an installation whose electrical cables are connected to a solar generator placed at the center of gravity, it is to make each year beyond amortization period, a considerable economy of the PV modules number to use, and thus a benefit of the cost of the central production.

7. Conclusion

- The obtained results, show that the cables cross sections have a very large importance in the optimization of an electrical network, in fact, the location of the generator (electric or solar) for the lowest annual cost of the investment depends on these electrical cross sections in contrast to time periods.

- In a context where the waste energy hunting becomes a duty, where each one should have the concern to facilitate the profitability of an investment, the consideration of the economic section is then the rule [16].
- The number of generators according to the loads used, can influenced the quantity of copper, thus the adoption of several generators can has an effective economical profit in terms of energy gain. This work will be the subject of our next study.

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